



## *Santalum austrocaledonicum* and *S. yasi* (sandalwood)

Santalaceae (sandalwood family)

*S. austrocaledonicum*: sandalwood (Vanuatu: Bislama)

*S. yasi*: *ahi* (Tonga); *yasi* (Fiji); *asi manogi* (Samoa)

Lex A. J. Thomson

### IN BRIEF

**Distribution** *S. austrocaledonicum*: New Caledonia and Vanuatu; *S. yasi*: Fiji, Niue, and Tonga.

**Size** Small shrubs or trees, typically 5–12 m (16–40 ft) at maturity.

**Habitat** Varies by species, typically subhumid or humid tropics with distinct dry season of 3–5 months.

**Vegetation** At young stages, dry forest and woodland; possibly closed secondary forest when mature in natural habitats.

**Soils** Requires light to medium, well drained soils.

**Growth rate** Slow to moderate, 0.3–0.7 m/yr (12–28 in/yr).

**Main agroforestry uses** Homegardens, mixed-species forestry.

**Main uses** Heartwood for crafts, essential oil extraction for cosmetics and perfumery, incense, and religious ceremonies.

**Yields** Heartwood in 30+ years (greater than 40 kg/tree [88 lb/tree]).

**Intercropping** Because sandalwood is hemiparasitic and requires one or more host plants, intercropping is not only possible, but necessary.

**Invasive potential** Has a capacity for invasiveness in disturbed places, but this is rarely considered a problem.



PHOTO: L. THOMSON

*Santalum yasi* seedling planted in homegarden, Pangaimotu, Vava'u, Tonga, and protected from damage by stakes.

## INTRODUCTION

Pacific sandalwood species are small trees that occur naturally in open, dry forests and woodland communities. They are typically multi-stemmed and somewhat bushy, attaining a height of 5–12 m (16–40 ft), or up to 15 m (50 ft) for *S. austrocaledonicum* in New Caledonia, at maturity and spreading to about the same width as their height. They are capable of root-suckering: following harvesting, clumps of suckers may regenerate in a circular pattern several meters away from the original stump. They are root-parasitic, which means they have special root extensions that capture nutrients from roots of certain other plants in the soil. Sandalwood cannot persist in moist, dense forest types due to its poor tolerance of high shade levels. Sandalwood species generally have a broad edaphic range, usually with a preference for well drained neutral to slightly alkaline soils. They grow more quickly in fertile soils but are more at risk of being shaded out by taller, faster growing trees on such sites.

Both *S. austrocaledonicum* and *S. yasi* have considerable economic potential, but their populations are depleted, and there is a need to promote greater regeneration and sustainably manage remaining populations. *Santalum austrocaledonicum* is currently being grown in small plantings or managed in natural stands in Vanuatu and New Caledonia in the southwest Pacific. The species grows at moderate rates and can produce substantial quantities of the valued heartwood on a rotation of about 25–40 years. There is a growing interest among villagers, other small-scale entrepreneurs, and government organizations to expand the scale of planting in both countries. Replanting of *S. yasi* is on a small scale, mainly within villages in areas where it naturally occurs. The largest replanting of *S. yasi* has been on the Tongan island of ‘Eua, where it has been successfully planted in association with *Pinus caribaea*.

The primary advantages of sandalwoods are their ability to produce a high-value, non-perishable product (heartwood) that can provide cash income to people living in outer islands and more remote communities. They may also be grown in environmentally sensitive areas, such as water catchment and biodiversity conservation areas, where extraction of a few small trees causes minimum disturbance while providing good economic returns.

Sandalwoods are well suited to interplanting, and due to their root-parasitic nature, they need to be grown with other suitable host tree species. They may be interplanted with various other species that can provide additional sources of revenue. In Tonga, sandalwood (*S. yasi*) has been grown with other commercial species including pine, casuarina, citrus, and paper mulberry. Sandalwoods have a

## SANDALWOOD TERMS

**Hemi-parasitic** Describes a plant which photosynthesizes but which derives water and some nutrients through attaching to roots of other species.

**Root-grafting** This is where roots of different individual plants grow together, forming functional unions and exchanging materials. Sandalwood roots can root-graft onto many other species, effectively joining whole plant communities through their root systems.

good regeneration potential and ability to colonize/invade nearby suitable sites. So long as some mature fruit-bearing trees are retained, birds will spread the fruit. Their invasive potential is seldom considered a drawback due to the exceptionally high value of their heartwood. Furthermore, their small stature and susceptibility to being shaded out means they never become dominant and/or substantially modify or replace existing plant communities.

## DISTRIBUTION

### Native range

***S. austrocaledonicum*** This species is naturally found in the island archipelagos of New Caledonia and Vanuatu in the southwest Pacific.

**Var. *austrocaledonicum*** is common in the Loyalty Islands and the Isle of Pines but is uncommon on the main island of Grande Terre. It is also present in the Belep islands. In Vanuatu the principal occurrence is around the northwest, west, and southwest portions of Erromango, and on the west coast of Espiritu Santo; it is also found on Tanna, Aniwa, Futuna, Malakula, Efate, and Aneityum.

**Var. *pilosulum*** is restricted to low elevations on the main island of New Caledonia near Noumea. It also has limited occurrence at high elevation in the Karaka region (northeast slope of Mt. Do between Boulouparis and Thio).

**Var. *minutum*** is restricted to the northwest side of the main island of New Caledonia.

***S. yasi*** This species occurs in lowland, drier, and more open forest types in Fiji, Niue, and Tonga. The Niuean population may be an ancient or Polynesian introduction. There is one record for Samoa (Savai‘i), where it appears to be introduced but not naturalized. The range extends from Niue and ‘Eua, a southern island in the Tongan group, through



**Left:** *Santalum austrocaledonicum*. PHOTO: L. THOMSON **Right:** *Santalum yasi* in Tonga. PHOTO: C. ELEVITCH

Tongatapu, Ha'apai, and Vava'u (Tonga), west and northwards, through the Fiji Islands (Lau group, Kadavu, Nausori Highlands/Viti Levu, Bua/Vanua Levu) to the Udu Peninsula, NE Vanua Levu, North of Fiji.

### Current distribution

*S. austrocaledonicum* Outside of its native range this species has limited planting, mainly for trial purposes in Australia, Fiji, and the Cook Islands.

*S. yasi* This species has limited planting outside of its natural range, mainly for trial purposes in Australia. Some of its occurrences, e.g., on Niue, may be comprised of naturalized populations following introduction by humans.

## BOTANICAL DESCRIPTION

### Preferred scientific names

*Santalum austrocaledonicum* Vieillard

*Santalum yasi* Seem.

### Family

Santalaceae (sandalwood family)

### Common names

*S. austrocaledonicum* sandalwood (Vanuatu: Bislama)

*S. yasi* *abi* (Tonga); *yasi* (Fiji); *asi manogi* (Samoa)

### Other common names

bois de santal, santal (French)

sándalo (Spanish)

sandalwood (English)

### Size

*S. austrocaledonicum* A shrub or a small tree typically 5–12 m (16–40 ft) tall by 4–8 m (13–26 ft) in crown width. The maximum tree dimension is 15 m (50 ft) tall by 10 m (33 ft) crown width. Maximum bole diameter at breast height is 40–50 cm (16–20 in).

*S. yasi* Mature trees typically grow to 8–10 m (26–33 ft) tall by 8–12 m (26–40 ft) in crown width, maximally reaching 15 m (50 ft) tall by 13 m (43 ft) in crown width. Maximum bole diameter at breast height is 40–50 cm (16–20 in).

### Form

*S. austrocaledonicum* and *S. yasi* Shrub to small tree typically with a short, crooked bole and spreading crown in open situations. In forest and sheltered situations, the



**Bark of *S. yasi*.** PHOTO: L. THOMSON

bole may be straight for more than half the total height. In older specimens the crown is light, straggly, and with drooping branches. The bark is smooth to rough, slightly longitudinally fissured or reticulated, which can be more pronounced with age, (greyish or reddish brown, mottled with patches of lichen).

### Flowering

The small flowers are clustered in terminal or axillary panicles about 4.5 cm (1.8 in) long. The bell-shaped flowers open to about 5 mm (0.2 in) across and have parts typically in fours. Buds and newly opened flowers have greenish white to cream-colored perianth segments (or tepals), remaining cream for *S. austrocaledonicum*, but turning light pink, through pink to dark red at maturity for *S. yasi*. Shorter, dark yellow disk lobes alternate with the tepals. The anthers are yellow and red-tinged for *S. yasi*, yellow for *S. austrocaledonicum*, and the style and stigmas are cream/pale yellow.

Under good conditions plants begin fruiting from an early age, typically about 3–4 years, but heavy fruiting may take 7–10 years. There is considerable variation in seasonality of flowering and fruiting. Trees flower and fruit throughout the year, usually with two peaks. The two main flowering periods for *S. yasi* in Fiji are October–November and February. In the southern islands of Tonga (‘Eua and Tongatapu), the main flowering period is (June–) July–August (–September). Further north in the Ha‘apai and Vava‘u groups the peak flowering period is November–December. For *S. austrocaledonicum* in Vanuatu, flowering occurs in January–April, July, and October. In New Caledonia, flowering occurs throughout the year, but there are flowering peaks in February and October, and flowering is rarely observed in June and July.

### Leaves

*S. austrocaledonicum* The foliage shows wide variation. Leaves are opposite, usually in one plane, decussate on erect new growth, simple, entire, glabrous, dark green, and shiny on top and dull light green to glaucous underneath. The shape of the leaf is initially long and thin (5–9 by 0.5 cm [2–3.5 by 0.2 in]) in seedlings and young plants to about 3 years of age, becoming shorter and broader in older plants. Mature leaves are narrowly elliptic, but maybe ovate, lanceolate, or obovate, (3–)4–6(–8) cm by (1–)1.5–2.5(–4.5) cm ([1.2–]1.6–2.4[–3.1] in by [0.4–]0.6–1[–1.8] in) with 6 to 15 pairs of barely visible secondary nerves tapering equally to the base and blunt tip. Var. *minutum* has smaller, more glaucous, bluish-green leaves, about 2 by 0.8 cm (0.8 by 0.3 in).

*S. yasi* Seedlings have very slender, near-linear, leaves. Leaves are simple, opposite, narrow to broadly lanceolate, shiny, and typically 6–7 by 1.5–2 cm (2.4–2.8 by 0.6–0.8 in). There is considerable variation in foliage size; adjacent plants have been observed to range from 5 by 1 cm (2 by 0.4 in) to 8 x 2.5 cm (3.1 x 1 in). The foliage is light to dark green, but plants growing in the open with few host trees available may have a yellowish-green appearance.

### Fruit

*S. austrocaledonicum* The fruit is a subglobose or ellipsoid, one-seeded drupe (7–20 mm [0.3–0.8 in] long by 10–15 mm [0.4–0.6 in] diameter), green and firm, ripening red, and turning purplish black and thinly fleshy when mature. Fruits have four longitudinal ridges and a square calyx scar at the apex. Fruits from Aniwa (Vanuatu) are much larger (20 x 15 mm [0.8 x 0.6 in]) than those from the Loyalty Islands (15 x 12 mm [0.6 x 0.5 in]). Mature fruits have been reported almost throughout the year, but the main fruiting season is November–January. In New Caledonia, two fruiting seasons are observed, in December–February (main fruiting season) and July–August (light fruiting season).

*S. yasi* The fruit is a one-seeded, ellipsoid drupe, ca. 12 mm (0.47 in) long by 11 mm (0.43 in) diameter with a small, round calyx scar (about 2 mm [0.08 in] diameter) at the apex, enclosing a rather stout, cone-shaped point. Immature fruits are light green, turning reddish-purple, and finally dark purple or black at full maturity. The main fruiting season corresponds to the wet season, January–March, with light fruiting in the cooler, dry season (June–August).

Fruits of both species mature about 4 months after flowering.



**Top left: Flowers of *Santalum austrocaledonicum*.** PHOTO: L. THOMSON **Top right: Mature fruit of *Santalum austrocaledonicum*.** PHOTO: L. THOMSON **Bottom right: Mature fruit and flowers of *Santalum yasi*.** PHOTO: L. THOMSON **Bottom left: Flowers of *Santalum yasi*.** PHOTO: C. ELEVITCH

### Seeds

The kernels consist of a hard (woody), smooth or slightly rough, light-colored endocarp enclosing a single seed.

*S. austrocaledonicum* Within var. *austrocaledonicum* the seeds from the Loyalty Islands are much bigger (2400 per kg [1100 seeds/lb]) than those from the Isle of Pines (6000 per kg [2700 seeds/lb]), while those from Vanuatu are intermediate (3300–4500 per kg [1500 seeds/lb]). Var. *pilosulum* has smaller seeds (8400 per kg [3800 seeds/lb]).

*S. yasi* The seeds are 9–11 mm by 6–7 mm (0.35–0.43 in by 0.24–0.28 in) with approximately 6000–7000 per kg (2700–3200 seeds/lb).

### Look-a-like species

Similar species include *S. album* (India, Indonesia, and Australia) and *S. macgregorii* (Papua New Guinea). To date, *S. album* has been little planted in the Pacific islands (Fiji, Tonga, Cook Islands, Samoa, and New Caledonia). The

species is in the process of becoming naturalized near old trial plots in northwest Viti Levu, Fiji, and has naturally hybridized with *S. yasi* where the two species have been planted together. *S. album* is the most well known and commercially traded sandalwood species, and its oil provides the international standard for sandalwood oil. The species is deeply ingrained in the philosophical, cultural, and religious ethos of Indian culture, and has been used for more than 2500 years.

### How to distinguish from similar species

Fruits are very useful for distinguishing related tropical species. In *S. album* the mature fruits are truncate-globose to ellipsoid; the raised calyx scar is up to about 5 mm across, forming an apical collar and enclosing the flat or slightly depressed disc that ends in a small point. In *S. macgregorii*, the fruit is a green, ovoid drupe (to 8–10 mm [0.3–0.4 in] long), turning purplish or bluish-black at maturity, and contains ellipsoid or sub-spherical seeds 4–6 mm (0.16–



**Left: Flowers of *S. album*.** PHOTO: C. ELEVITCH **Right: Mature fruit of *Santalum album*.** PHOTO: L. THOMSON

0.24 in) long by (2–)2.5–4.5(–5) mm ([0.08–]0.1–0.18[–0.2] in) wide, with three to four ridges at the pointed end.

## GENETICS

### Variability of species

All *Santalum* species exhibit considerable morphological variation, and numerous traditional varieties are recognized. There are three formally described varieties of *S. austrocaledonicum* in New Caledonia, as well as two heartwood chemotypes in Vanuatu. One chemotype produces heartwood oils rich in santalols ( $\alpha$ -santalol >30–40% and  $\beta$ -santalol >15%) while the other chemotype heartwood oil is rich in Z-nuciferol (7–25%) and/or Z-lanceol (15–41%), with lower concentrations of santalols.

### Known varieties

*S. austrocaledonicum* var. *austrocaledonicum* and var. *pilosulum* have large leaves (about 5 by 2 cm [2 by 0.8 in]) and long petioles (6–16 mm [0.24–0.63 in]) and tepals (1.3 x 0.8 mm [0.05 by 0.03 in]). The flowers and new shoots of var. *austrocaledonicum* are glabrous whereas those of var. *pilosulum* are villous or hairy. Var. *minutum* has much smaller leaves (about 2 by 0.8 cm [0.8 by 0.3 in]) and tepals (1.3 by 0.4 mm [0.05 by 0.02 in]).

## ASSOCIATED PLANT SPECIES

*S. austrocaledonicum* In New Caledonia it mainly occurs in secondary forests and agricultural fallows in the Loyalty Islands. In dry forest (Grande Terre), it is often associated with *Acacia spirorbis*, *Croton insularis*, and *Arytera collina*. It also sometimes occurs with grasses, such as *Panicum maxi-*

*mum*, on plains and with ruderal species (families Fabaceae, Asteraceae, and Convolvulaceae). Var. *minutum* occurs in scrubland, with various shrub species including *Cassinia trifoliata*, *Xanthostemon pubescens*, *Hibbertia deplancheana*. In Vanuatu it frequently occurs with *Acacia spirorbis*, low shrubs, and Cyperaceae. Other associated plant species include coconut, grasses, bamboos, *Cryptocarya turbinata*, *Hibiscus tiliaceus*, *Dracontomelon vitiensis*, *Garuga floribunda*, *Leucaena leucocephala* (introduced), and *Pterocarpus indicus*.

***S. yasi*** *Yasi* is mainly found in open forest types (often with a grassy understory), including secondary forests developing in old garden sites. In Tonga, some trees were found in young dense forest on the islands of Vava'u, establishing themselves when the surrounding trees were smaller and the stand had been opened up for cultivation of agriculture crops. It also occurs in low coastal forest associations on small coralline islands. In Fiji associated woody species include *Acacia richii*, *Casuarina equisetifolia*, *Calophyllum vitiense*, *Cocos nucifera*, *Fagraea gracilipes*, *Storckiella vitiensis*, *Hibiscus tiliaceus*, *Thespesia populnea*, and *Dodonea viscosa*. Associated species in Tonga include *Broussonetia papyrifera*, *Citrus* spp., *Diospyros* spp., *Hernandia nymphaeifolia*, *Inocarpus fagifer*, *Morinda citrifolia*, *Pandanus tectorius*, *Pometia pinnata*, and *Rhus taitensis*.

### Species commonly associated in modern introductions

Both species have been successfully interplanted in *Pinus caribaea* plantations on 'Eua, Tonga. They are often planted in Fijian village homegardens with ornamentals and cultural species (e.g., *Pandanus tectorius*, *Polyscias*, *Croton*, *Cordyline*, and *Euodia hortensis*) and fruit trees (e.g., *Artocarpus altilis*, *Citrus* spp., *Musa* spp., and *Pometia pinnata*).

## FOLK VARIETIES

In Vanuatu, two folklore varieties of *S. austrocaledonicum* are widely distinguished. These are a “man” variety known variously as *pior laman* (Penour, Valpei; West Santo), *initjinyat atamien* (Anelghowhat, Aneityum), and man *nipigisi* (Port Patrick, Aneityum), and a “woman” variety called *pior akae* (Penour, Valpei), *initjinyat ataheig* (Anelghowhat), and woman *nipigisi* (Port Patrick). The man variety is characterized as a taller tree, with longer bole, longer pointed leaves, producing few or no fruits, while the woman variety has a shorter, fatter bole, smaller branches, a more rounded leaf, and produces many more fruits. The woman variety produces good heartwood early, whereas the male tree needs to be pruned to induce good heartwood.

Several folk varieties of *S. yasi* have been reported in Fiji and Tonga. The varieties reported from Fiji include *yasi dina* (or true sandalwood, i.e., *Santalum*, distinguishing it from other genera that have sweetly fragrant wood), *yasi boi* (fragrant), *yasi buco*, *yasi vula* (white), *yasi damu* (red), and *yasi kula* (red). The latter folk variety has reddish leaves (possibly a micronutrient disorder) and strongly scented heartwood. Varieties reported from Tonga include *fefine* (literally female, with small leaves), *tangata* (with large, long leaves), *kolo* (sweet smelling), *lau labi*, *ubiubi*, and *vao*. These varieties mainly refer to particular phenotypes in a population rather than whole populations. In both Tonga and Fiji the identity and morphological traits of these folk varieties may be interpreted somewhat differently by different villagers/villages.

## ENVIRONMENTAL PREFERENCES AND TOLERANCES

### Climate

*S. austrocaledonicum* and *S. yasi* prefer warm to hot, lowland, subhumid or wet/dry tropics, with an annual rainfall of 1250–1750 mm (50–70 in) and a distinct dry season of 3–5 months. Tropical cyclones are a feature of the entire distribution, occurring mainly during the hot, wet season (December–April).

### Elevation

*S. austrocaledonicum* 5–800 m (16–2400 ft), usually less than 300 m (1000 ft) in New Caledonia  
*S. yasi* 0–300(–600) m (0–1000[–2000] ft)

### Mean annual rainfall

*S. austrocaledonicum* 800–2500 mm (30–100 in)

*S. yasi* 1400–2500 mm (55–100 in)

### Rainfall pattern

All species prefer climates with summer rains.

### Dry season duration (consecutive months with <40 mm [1.6 in] rainfall)

Most localities experience a pronounced dry season of 2–5 months during the cooler months June–October (Southern Hemisphere).

### Mean annual temperature

*S. austrocaledonicum* 23–27°C (73–81°F)

*S. yasi* 23–29°C (73–84°F)

### Mean maximum temperature of hottest month

*S. austrocaledonicum* 29–33°C (84–91°F)

*S. yasi* 24–31°C (75–88°F)

### Mean minimum temperature of coldest month

*S. austrocaledonicum* 16–22°C (61–72°F)

*S. yasi* 18–25°C (64–77°F)

### Minimum temperature tolerated

*S. austrocaledonicum* The absolute minimum temperature is 10–16°C (50–61°F), but possibly as low as 5–7°C (41–45°F) on Mare, Loyalty Islands, New Caledonia.

*S. yasi* The absolute minimum experienced is around 8–9°C (46–48°F) at the higher elevations sites in western Viti Levu.

For both species the entire distribution is frost-free.

### Soils

*S. austrocaledonicum* The species grows well on pure coralline soil, volcanic ash, schist or sedimentary substrates. The species prefers well drained acidic to alkaline conditions and does not grow well on waterlogged soils and strongly acidic clayey soils.

*S. yasi* In Fiji the soils are mainly well drained, humic and ferruginous Latisols. In Tonga, its best development is on soils derived from volcanic ash overlying coralline rock.

### Soil texture

The trees prefer light and medium, well drained soils (sands, sandy loams, loams, and sandy clay loams).

### Soil drainage

Both species require freely draining soils.

### Soil acidity

Both species may grow on acid to alkaline soils (pH 4.0–7.4), but prefer neutral soils (pH 6.1–7.4).

### Special soil tolerances

Both species can tolerate shallow and infertile soils. In the Poya region of New Caledonia, var. *austrocaledonicum* grows in ferrallitic/ultramafic soils with a limestone substrate. These soils have high levels of exchangeable calcium and potassium and are rich in nickel and chrome. Further north, around Pouembout, it grows in a highly acidic to neutral, magnesium-rich black clay derived from basalt. Var. *minutum* occurs on immature colluvial soil on serpentine peridotite/metamorphic and ultramafic gravels. Such soils are infertile with very low levels of phosphorus, potassium, and calcium, but are relatively high in magnesium, nickel, chrome, and manganese.

### Tolerances

#### Drought

They are able to survive a long dry season (up to 5–6 months) when attached hemi-parasitically to suitably drought-tolerant host plants.

#### Full sun

They grow well in full sun when their roots are attached hemi-parasitically to suitable host species; otherwise, they become yellow (and can die).

#### Shade

They can survive up to 60–70% shade, but growth will be very slow at higher shade levels. The optimum level of shade is up to about 25%, preferably as “side shade.” Side shade is provided by planting adjacent rows of bushy but not spreading plants, which grow up to about the same height as sandalwood but do not overtop and cast overhead shade.

#### Fire

Both species are sensitive to fire (and grazing from cattle and deer) particularly in the first few years of growth. Plants of some sandalwood species will regrow from coppice following fire; e.g., *S. austrocaledonicum* and younger specimens of *S. album*.

#### Frost

Both species are frost-sensitive.

#### Waterlogging

They prefer good drainage and will die or die back following any prolonged period (greater than 2 weeks) of waterlogging.

#### Salt spray

Plants growing in near-coastal situations may suffer severe

scorching by salt-laden winds and total defoliation following cyclonic storms, but usually they totally recover.

### Wind

Mature plants are typically of low stature and are generally fairly resistant to strong winds associated with cyclonic storms, except in open areas. Younger plants in open areas, especially if they have grown quickly and have a heavy canopy, may be blown over or suffer breakage of stems and branches. Older trees growing among established forests can also suffer from limb damage during cyclone events. The most susceptible trees are those with forked trunks, which can easily split.

## GROWTH AND DEVELOPMENT

### Growth rate

*S. austrocaledonicum* In New Caledonia in young plantations (up to 5 years) individuals show mainly an increase in height with a mean annual growth increment in trunk diameter of about 6 mm. The average diameter growth rate in older plants is 3.8–4.8 mm per year. In Vanuatu young plants (up to 3 years old) can grow at moderately fast rates, e.g., 1 m height per annum and 1 cm diameter increment (measured at 20 cm above ground level) per annum. Diameter growth averaged 6–10 mm per year at 18–26 years, and 6–7 mm per year after 28–33 years. Trees can grow at moderate rate over the projected rotation period of about 25–40 years.

*S. yasi* Early height growth is slow to moderate, e.g., 0.5–0.7 m per year, but is variable depending upon environmental conditions and host species. Under suitable growing conditions it may attain harvestable size in about 25 years; e.g., 20–25 cm diameter near ground level, with substantial heartwood development.

### Rooting habit

Sandalwoods have a widely spreading surface root system capable of grafting onto many other plant species and tapping water and mineral nutrients.

### Reaction to competition

Sandalwoods, especially as young plants, react poorly to competition from monocotyledons (including grasses and palms such as coconut). Being hemi-parasitic, they are best grown in close proximity to suitable host species.

### Diseases and Pests

*S. austrocaledonicum* In New Caledonia plants are sometimes attacked by insects (*Ceroplastes* and *Coccus*), but dam-



age is rather minor. Fungal damage has been observed on leaves of nursery seedlings. Plants are susceptible to brown root rot (*Phellinus noxius*).

***S. yasi*** *Yasi* is susceptible to *Phellinus noxius*, and mature specimens may quickly succumb to it. This disease is potentially serious, as it can spread rapidly to adjacent trees through root grafting. In cool, wet, cloudy weather, seedlings can be attacked by a fungus (anthracnose type) that can cause severe leaf spotting (hypersensitive reaction) followed by defoliation. Seedlings are susceptible to root rot-fungi in poorly draining and unsterilized media. *Yasi* is also susceptible to sandal spike disease, caused by a mycoplasma-like organism; this pathogen causes considerable damage to *S. album* in India (but is absent from the South Pacific region).

## ABILITIES

### Regeneration

Regeneration of wild sandalwood stands typically occurs very slowly following harvesting due to the removal of most of the larger fruiting specimens, and in at least some cases the removal of other species upon whose roots the sandalwood plants parasitize.

### Self-prune

Self pruning is variable; in open situations, sandalwood plants often retain branches to near ground level. In shadier situations, especially where the shade is cast from overhead, the plants exhibit reasonably good self-pruning characteristics. For *S. yasi* suitable shade regimes to keep plants growing straight and to avoid a bushy habit include strong lateral shade with no overhead shade or a high canopy producing intermediate shade.

### Coppice

Plants frequently resprout from basal coppices or by root suckering off lateral roots (following removal of the stump and major roots). Many species are capable of root suckering as long as not too much of the root system is removed during harvest. However, such coppice regrowth is likely to die out in more heavily shaded situations.

### Pollard

Plants can be pollarded, but this is not an appropriate regime for sandalwood where the economic value is concentrated in the heartwood in the lower bole and large woody roots.

## PROPAGATION

All *Santalum* species are readily propagated by seed in the nursery. They may also be propagated through encouraging seedling development underneath selected heavy-bearing plants; such wildlings can be transplanted to a new location. Vegetative cuttings may be struck under mist from seedling material. Cuttings from young plants initiate and develop adventitious roots much more readily than cuttings from more mature plants. Grafting and root segment cuttings from mature specimens can be used to conserve selected individuals or bring them into breeding programs.

### Propagation by seed

#### Seed collection

It is recommended that mature fruits be collected while still attached to the tree, although recently fallen fruits may also be acceptable if not exposed to the sun. Fruits that have attained maturity are full size and usually have begun to show slight color change, commonly a reddish tinge, the fruit becoming entirely red to dark purplish black.

***S. austrocaledonicum*** The main fruit collection period is from November to January.

***S. yasi*** The main fruit collection period is from January to March.

#### Seed processing

The fleshy mesocarp needs to be removed from the fruits without delay. Fruits that are hard to depulp by hand may be soaked in water for 1–2 days to soften the pulp prior to its removal. The depulped, cleaned seeds are then disinfected (e.g., with sodium hypochlorite or diluted bleach) before being rinsed and air dried in a well ventilated room



When picked green, fruits are rarely viable. A reddish or purplish tinge is a first indication that seeds are mature. Pictured: *S. album*. PHOTO: L. THOMSON

at a temperature below 25°C (77°F) out of direct sun for up to 2–3 weeks. Seeds usually have a high purity, but number of viable seeds per kg varies considerably between species, provenances, and individual seed lots.

Depending on the seed source, there are 2400–8400 seeds per kg (1100–3800 seeds/lb):

*S. austrocaledonicum* Loyalty Islands: 2400 per kg (1100 seeds/lb); Isle of Pines: 6000 per kg (2700 seeds/lb); Vanuatu: 3300–4500 per kg (1500–2000 seeds/lb)

*S. austrocaledonicum* var. *pilosulum* 8400 per kg (3800 seeds/lb)

*S. yasi* 6000–7000 seeds per kg (2700–3200 seeds/lb)

For newly collected seed, viability is high for *S. yasi* and *S. album*, often 80–90% after 2–3 months, for naked seed (embryo extracted). Germination is lower for nicked seed, e.g., 60–70% after 3 months, and lower and much slower for untreated seeds.

### Seed storage

Many *Santalum* species show intermediate storage behavior, with seeds rapidly losing viability during storage. Seed storage behavior varies between species, and may even vary among different seed sources for *S. austrocaledonicum*. For example, seeds from the Isle of Pines may be safely stored for several years, whereas those from the Loyalty Islands lose viability within a few months. Seed storage behavior for *S. yasi* is unknown, but seeds stored for longer periods (>6–12 months) will have very low viability. *S. album* has an orthodox seed storage behavior, but viability generally declines after several years in storage.

Seed for storage should be placed in airtight containers in the refrigerator (2–4 °C [36–39 °F]) as soon as possible following surface drying. In general, ultra-dry storage (e.g., down to about 2% moisture content) is recommended for seeds of high oil content that are normally short-lived in storage.

It is usually preferable to sow sandalwood seed as soon as possible after collection to reduce the risk of the seeds losing viability during storage.

### Pre-planting treatments

For *S. austrocaledonicum*, pretreatment of seed promotes rapid and uniform germination. The

recommended seed pretreatment method is as follows:

1. Nick the seed coat at the pointed end of seed using a sharp knife.
2. Soak seeds overnight in a solution of gibberellic acid (GA<sub>3</sub>) at rate of 0.1 to 0.25 g/l.
3. Drench the seeds in a fungicidal solution, e.g., benlate,



**Top:** *Santalum* seeds sprouting in pure vermiculite. PHOTO: C. ELEVITCH  
**Bottom:** *S. yasi* in containers with host plants *Calliandra calothyrsus* (foreground), *Casuarina equisetifolia* (middle), and *Alternanthera* sp. (background). PHOTO: L. THOMSON

for a few minutes before sowing (optional).

Treatment of freshly collected seed with gibberellic acid (GA) gives quick and homogeneous germination but is not recommended for routine nursery production of seedlings due to high cost. GA treatment might best be used for smaller, more precious research samples, etc.

The following treatment has been shown to produce quick germination of the Hawaiian species *S. ellipticum* and *S. freycinetianum*. Before treatment, seeds should be removed from the ripe fruit, cleaned by hand, and air-dried for about a week. Then a small part of the seedcoat at the apex of the seed should be removed so that the embryo becomes visible but not damaged. This can be done using large nail clippers, forceps, or medium sandpaper. Subsequently, the seed can be soaked in small amounts (0.05%) of the plant hormone gibberellic acid for 5 days, changing the solution daily. Then the seed is removed from the growth hormone solution and dusted with a 1:1 mixture of powdered sulfur and captan to prevent fungus infection. Seeds should be placed in a covered tray on new, wet vermiculite to allow germination to occur.

### Growing area

Seeds are generally germinated under cover in a glasshouse (or other covered nursery structure) in a freely draining medium, e.g., 1:1 sterilized river sand, peat moss mixture, or 2:1 sand:compost. The mixture should be kept slightly moistened (but not wet, in order to avoid rotting of seeds and damping off). The optimum temperature for germination is 28–31°C (82–88°F). Germination trays should be protected from rats, birds, and other predators that will eat seeds or young germinants.

As seedlings age they are moved to progressively higher light levels, e.g., 50% shade in the early months, then 25% shade and several months of hardening under full sun prior to field planting.

### Germination

*S. austrocaledonicum* Nicked seed commences germination after 2 weeks and is completed by 8 weeks; most germination occurs between 30 and 40 days. Whole seed is much slower to germinate, commencing after about 40 days. Germination rates of greater than 50% are expected for fresh seed that has been collected from mature fruits still on the tree and appropriately handled and cleaned.

*S. yasi* Germination of nicked seed occurs rather slowly over a long period, e.g., from 40 to 120 days after sowing. As they appear, germinants are transplanted into pots, preferably before the seed coat falls from the germinating shoot.

Seedlings are pricked out at the two- or four-leaf stage

## RECOMMENDED HOSTS

*Acacia* species, *Calliandra calothyrsus*, and *Casuarina* spp. may be used as pot hosts, but *Calliandra* needs frequent cutting back to prevent it from overtopping the sandalwood.

*S. austrocaledonicum* *Acacia spirorbis* makes a good long-term host plant under both natural conditions and in plantations. For ultramafic soils, other good nitrogen-fixing host species are *Casuarina collina* and *Gymnostoma deplancheana*.

*S. yasi* Good long-term hosts include *Citrus* spp., *Acacia richii*, *Calliandra calothyrsus*, and *Casuarina equisetifolia*.

*S. album* Good intermediate and long-term hosts include *Acacia trachycarpa*, *Casuarina junghuhniana* (long-lived), *Cathormium umbellatum* (long-lived), *Crotalaria juncea*, *Desmanthus virgatus*, and *Sesbania formosa*.

into polybags (16 x 6.5 cm [6.3 x 2.6 in]). At this time a host plant is usually planted together with the seedling (see “Recommended hosts” sidebar).

### Media

The potting mixture should be well drained with reasonable water-holding capacity. A typical growing medium for *S. yasi* in Fiji is a moderately fertile, forest loam (67%), and river sand (33%) plus 2 kg NPK fertilizer per cubic meter (2 oz/ft<sup>3</sup>).

### Time to outplanting

Seedlings are ready for planting when the height is about 20–25 cm (8–10 in), usually taking approximately 5–6 months.

### Guidelines for outplanting

Sandalwoods need to be either planted out among established long-term host plants, or else together with intermediate hosts (relatively short-lived woody perennials) while longer term hosts are established.

Survival rates are high (often above 80%) for larger, healthy seedlings planted at the onset of the rainy season and kept well weeded in the first 2 years. Survival and growth will be low for plants

- established in more shady forest situations
- in grassy, sunny situations
- in polycultures underneath coconut plantations.



**S. yasi seedling ready for outplanting.** PHOTO: L. THOMSON

### Propagation using wildlings

The following technique is useful for promoting germination of wildlings, which can then be transplanted and grown in the nursery before field planting in a suitable location:

- Select sandalwood trees that are fruiting or are otherwise known to fruit heavily.
- Clean all undergrowth from beneath the canopy of the selected sandalwood trees.
- Loosen the soil in the cleared area by shallow digging or cultivating only the top 5 cm (2 in) of soil.
- Wildlings begin to germinate in the cultivated area about 1–2 months after soil disturbance.
- If possible water the cultivated area during dry periods or after some germinants are observed.
- Keep the cultivated area free from regrowth of weeds.

### Propagation by vegetative cuttings

Rooting of cuttings varies considerably between species and half-sibling families, and rooting success declines rapidly with stock plant age. Successful root initiation and development to a level of greater than 40%, can only be ob-

tained using shoot material collected from seedlings and struck under intermittent misting in suitable media (e.g., 1:1 sand/peat or 1:1 sand/coconut coir). The order of ease of rooting is *S. yasi* > *S. austrocaledonicum* > *S. macgregorii* > *S. album*. There is a need for further work to identify appropriate stock plant treatments and environmental conditions to optimize rooting success for each species.

### Propagation by root cuttings

Root segments (about 5–10 cm [2–4 in] long and greater than 1 cm [0.4 in] in diameter) may be collected from larger specimens of *S. album* (and probably other sandalwood species) and used to strike cuttings. The cuttings are treated with rooting powder (e.g., Seradix B<sub>2</sub>) and placed horizontally at a depth of 1 cm [0.4 in] in a freely-draining medium (e.g., 50:50 coarse washed river sand and peat moss) which is kept moist (but not saturated) in a glass-house (or alike). The time for sprouting is from about 1 to 3 months. The percentage of root segments forming shoots and roots is typically low (e.g., 10–50%) and dependent on



**Freshly dug up *S. austrocaledonicum* seedlings for immediate transplant to other areas on the island of Aniwa, Vanuatu.** PHOTO: T. PAGE



Young *S. austrocaledonicum* seedling with artificial shelter, Efate, Vanuatu. PHOTO: L. THOMSON

seasonal factors.

## DISADVANTAGES

The main drawbacks of sandalwood cultivation are:

- lack of seed and planting materials
- lack of varieties or cultivars with known oil qualities and yields
- relatively complex silviculture and need to be grown with suitable host plant species
- susceptibility to root and butt rot fungi and rapid death of plants when grown in higher rainfall zones
- risk of theft of trees when nearing maturity.

### Potential for invasiveness

Pacific island sandalwoods have not become naturalized outside of their native range. Sandalwood species generally have a capacity for invasiveness in disturbed, open plant communities, but this is not considered a problem because of their very high value and because they do not dominate or appear to modify such communities in any substantial way. There is a risk that some planted host species, especially exotic leguminous trees, might become invasive. Accordingly, it is recommended that local plant species are screened first for suitability as hosts and used preferentially as hosts, especially in and around areas of high biodiversity conservation value.

Sandalwood species are root parasites, with the potential to root-graft and link almost whole plant communities. They are therefore at particular risk of pathogenic fungi that can also spread from tree to tree through root grafts, such as *Phellinus noxius*.

### Host to crop pests/pathogens

Sandalwood species are not known to be an important host of any crop pests or diseases.

### Other disadvantages or design considerations

These trees need to be planted in well protected areas in which opportunities for theft are minimized, such as in homegardens, smaller remote islands, and well fenced and closely guarded locations. Fencing is also necessary in areas with wild steers because of their feeding preference toward developing sandalwood saplings.

## AGROFORESTRY/INTERPLANTING PRACTICES

### Alley cropping

Sandalwoods are suitable for inclusion in alley cropping systems, especially where the other alley species include good hosts, e.g., *Calliandra* spp.

### Homegardens

They are very suitable for planting in homegardens, which have the advantages of mixture of host species, intermediate/variable light levels, and high security.

### Improved fallows

They could be included in improved fallows of nitrogen-fixing trees, with a fallow rotation of 20 or more years to ensure that sandalwoods attain commercial maturity.

### Windbreaks

Sandalwoods are suitable for inclusion in windbreaks, especially where the main windbreak species include good hosts, e.g., *Casuarina* spp.

### Woodlot

Sandalwoods are suitable for inclusion in woodlots, especially when planted along sun-exposed edges of the woodlot and in combination with compatible species, e.g., with *Pinus caribaea*, as has been done in Tonga.

### Native animal/bird food

The fruits of sandalwood are consumed by various bird species, including pigeons. For soft-beaked species the seeds may pass through the digestive system intact and be widely disseminated.

### Host plant trellising

There is minor potential to trellis slower-growing vines that would not interfere with full sun reaching the canopy,



Left: *S. yasi* grown on fence line between two house lots in Tonga. Right: *Alyxia stellata*, a traditional vine used in garlands, climbing on yasi in a home garden in Tonga. PHOTOS: C. ELEVITCH

such as maile (*Alyxia stellata*).

### Ornamental

Sandalwoods are quite attractive, especially when in flower, and are especially suitable for home and village gardens.

## USES AND PRODUCTS

Wood from sandalwood was traditionally used in the South Pacific for carvings, cultural uses, medicine, and burnt as an insect repellent. However, it is rarely used nowadays because of its scarcity and cash value. The grated wood was traditionally used to a limited extent to scent coconut oil (for application to the hair and body) and cultural artifacts such as tapa cloth.

Both *Santalum austrocaledonicum* and *S. yasi* produce highly prized sandalwoods, often similar in quality to the well known *S. album* from India and Indonesia. The heartwood of *S. yasi* was a major export during the early 1800s, and the sandalwood trade was one of the first attractions drawing Europeans into the South Pacific. Sandalwood from *S. yasi* is still exported to a limited extent from Fiji and Tonga, experiencing short-lived boom periods associated with a

buildup of sandalwood stocks, the most recent in Fiji being in the mid-late 1980s when a ban on commercial exploitation was lifted. *S. austrocaledonicum* was heavily exploited over about three decades in the middle of the 1800s in New Caledonia and Vanuatu, and it has been utilized periodically since. Carvings, sandalwood oil, and incense production, listed in order of highest to lowest value, are the three major present-day wood uses of *S. austrocaledonicum*.

### Medicinal

Sandalwood has various and generally not well documented medicinal uses. In Samoa, a decoction of sandalwood and *Homolanthus* leaves is taken to treat elephantiasis or lymphatic filariasis.

### Craft wood/tools

The highest-value sandalwood is used for carving (religious statues and objects, handicrafts, art, and decorative furniture). Larger basal pieces and roots are preferred for carving.

### Cosmetic/soap/perfume

The oil from the heartwood, extracted by steam distilla-

tion or by solvent, is used for cosmetics, scenting of soaps, perfumery, aromatherapy, and medicinal purposes. The oil content of heartwood varies considerably among species, individual trees, and location within the tree, but is typically in the range of 3–7% for basal stem/large root sections. Oil is currently distilled from *S. austrocaledonicum* and *S. album*, but not *S. yasi* (due to lack of supply).

### Ceremonial/religious importance

Heartwood from sandalwood trees yields an aromatic oil that is widely valued and has been the basis of a lucrative and exploitative trade for hundreds of years. In Tonga, the oil is used to scent tapa cloth and anoint corpses in royal funerals. *S. yasi* is also featured in Tongan legends and songs. Heartwood and sapwood are powdered together to produce incense or joss sticks used in Asian religious ceremonies. Sawdust, wood shavings from carving or wood residue after oil distillation may be used.



Sandalwood sculptures Bangalore, India. PHOTO: M. MERLIN

## COMMERCIAL PRODUCTS

The primary commercial products from sandalwood are the heartwood and the essential oil distilled from the heartwood. The international standard for the oil of *S. album* (ISO/DFIS 3518) includes four compounds in the chromatographic profile ( $\alpha$ -santalol, trans- $\alpha$ -bergamotol, epi- $\beta$ -santalol, and Z- $\beta$ -santalol), but only two, Z- $\alpha$ -santalol (41–55%) and Z- $\beta$ -santalol (16–24%), are assessed in the standard. The total santalol content of *S. yasi* oil (the component most associated with sandalwood's essence) is 60–70% and similar to that of *S. album* (the industry standard and most sought-after oil). The composition of heartwood oil from *S. austrocaledonicum* from New Caledonia (Maré Island and Isle of Pines) resembles *S. album*, with very similar levels of the major fragrant constituents, 48–49%  $\alpha$ -santalol and 20–22%  $\beta$ -santalol. In Vanuatu there are two chemotypes of *S. austrocaledonicum*, one chemotype being rich in santalols (>30–40%  $\alpha$ -santalol and >15%  $\beta$ -santalol) while the second chemotype contains Z-nuciferol (7–25%) and/or Z-lanceol (15–41%) and lower proportions of santalols.

The heartwood from Pacific sandalwood species is mainly exported to Asia. Most *S. yasi* from Tonga gets exported to East Asian countries, particularly China (via Hong Kong), Taiwan, and Japan, but some is also supplied to the United States. The main markets for sandalwood oil are Europe and the United States.

### Spacing for commercial production

Spacing for commercial production varies considerably depending on the type of planting. The final crop is likely to be around 100 mature sandalwood trees per hectare (10 x 10 m [33 x 33 ft]) due to need to include host tree/shrub species (at a rate of 2–4 per sandalwood depending on host species). Due to the high value and demand for even a single mature tree, there is effectively no minimum area or number of trees required for commercial production. The plantation area required to provide raw material for a small/medium scale oil distillation operation of *S. austrocaledonicum*, e.g., producing 800 liters per annum (845 qt/yr) from 20–40 mt (22–44 t) of heartwood, is estimated to be about 60–120 ha (150–300 ac), based on a 30-year rotation.

### Management objectives

The main management objective should be to establish and manage a good mixture of host plant species that provide a suitable light/shelter regime.

Host tree species may need to be pruned or progressively thinned to maintain good levels of sunlight to maturing sandalwood plants.

For *S. yasi* careful pruning of side branches, removing no more than 25% of canopy at any one time, has been advocated to encourage development of a main bole. Regular removal of competing leaders (breaking by hand) in younger specimens may be a more satisfactory approach.

For soils of lower fertility, periodic fertilizing with 100 g (3 oz) NPK fertilizer per tree will promote more rapid growth.

Weed growth, especially of long, flammable grasses, needs to be well controlled in the early years. Weeds should be manually removed to avoid the risk of herbicide drift and/or translocation through weeds to sandalwood plants via root system connections.



**This brush-like regrowth with stunted leaves is indicative of herbicide poisoning, in this case translocated from weeds that were poisoned near this *S. album* tree.** PHOTO: C. ELEVITCH

### Design considerations

Greater accessibility of sandalwood plantations increases the risk of theft.

### Advantages and disadvantages of growing in polycultures

A diverse mixture of host species is preferred so as to:

- enable sandalwood trees to optimally obtain their mineral nutrition/water needs, and,
- reduce pest and disease risks associated with reliance on just one or two main hosts.

### Estimated yields

*S. austrocaledonicum* A rough estimate of heartwood production is 50–100 kg (110–220 lb) per tree after 30 years.

*S. yasi* With good silviculture, it is estimated that trees can produce about 1–2 kg (2.2–4.4 lb) of heartwood each year from age 10 years. Therefore a 20–25-year-old tree, growing

under good conditions, can produce 15–30 kg (33–66 lb) of heartwood (including from roots).

*S. album* It is estimated that trees can produce about 20–40 kg (44–88 lb) of heartwood on a 20 year rotation, under South Pacific conditions and given appropriate silviculture.

### On-farm processing

Whole trees including major roots are harvested. The main on-farm processing is careful removal of the sapwood, using a large, sharp knife. Sandalwood wood pieces that are kept in dry conditions for several months may exhibit small increases in oil content and improvement in quality (but this is offset by a lower weight and hence return to the grower).

### Markets

The world production/consumption of sandalwood oil is in the order of several hundreds of metric tons. India is the major producer (90% of world production) and user of sandalwood oil. Exports from India of *S. album* oil during the 6 year period 1987/88–1992/93 averaged 40.5 mt (45 t) with the main importers of this oil being France and the United States. Indonesian exports of *S. album* oil during 1987 to 1992 averaged 15 mt/yr (17 t/yr) and went mainly to the U.S., which is the single largest market outside India. International demand for *S. album* oil is not being met, and prices continue to rise. Markets for *S. austrocaledonicum* oil, up to about 15–20 mt (17–22 t) per year, include France, Germany, and the United States.

Annual global sandalwood heartwood production is estimated to be approximately 5100 mt (5600 t), however, production has declined markedly over the past 20–30 years. China, Taiwan, Singapore, Korea, and Japan, with no natural resources of sandalwood, are the main markets, together with India, which has its own production capability. Production of sandalwood heartwood from the South Pacific is highly variable, experiencing periods of boom and bust since exploitation commenced in the early 1800s.

## INTERPLANTING/FARM APPLICATIONS

### Example system 1

#### Location

South Efate, Vanuatu

#### Description

This is a recently developed system (since 1997) of growing



sandalwood (*S. austrocaledonicum*) in planted lines as part of a mixed farming enterprise following recommendations provided by the South Pacific Regional Initiative on Forest Genetic Resources (SPRIG) Project. Sandalwood plants are established either using seedlings or direct-seeding.

### Yields

Plants are healthy, bushy, and have shown good growth, e.g., about 1 m (3.3 ft) height growth per year. The previous system had been to plant sandalwood seedlings underneath residual remnant forest, which resulted in very slow growth due to insufficient light.

### Crop/tree interactions

The lines of sandalwood are interplanted with lines of *Casuarina* (every third line) that act as a permanent host and windbreak. Intermediate hosts included vegetable crops such as *Capsicum*.

### Spacing

The spacing is about 3 m (10 ft) between and within double rows of sandalwood trees with every third row comprising *Casuarina*.

## Example system 2

### Location

Tanna, Vanuatu

### Description

This is a recently developed system (since about 1996) in which sandalwood (*S. austrocaledonicum*) wildlings are transplanted around the perimeter of new village garden areas established within bush and secondary forest.

### Yields/Benefits

Plants are healthy and have shown good stem form and early growth, e.g., about 1 m (3.3 ft) height growth per year. Sandalwood grows very well along forest edges/verges, due to the good balance of light and hosts, and this system takes advantage of this.

### Crop/tree interactions

On the bush/forest side of the plot, the sandalwood plants gain access to root systems of diverse permanent hosts and receive some side and overhead shade, which encourages better stem form. On the garden side, sandalwood plants have the advantage of good weed control plus high levels of sunlight. The main crop was

ginger, but this system would work well with almost any vegetable or root crop.

### Spacing

The sandalwood trees are planted in a line along the boundary perimeter of the garden area. Spacing is variable, about 3–4 m (10–13 ft) between trees.

## Example system 3

### Location

‘Eua, Tonga

### Description

This is a recent system dating from the early 1990s involving interplanting of *S. yasi* in a *Pinus caribaea* plantation.

### Yields

Sandalwood trees in pine plantations appear to reach 8–12 m (26–40 ft) in height and 15 cm (6 in) in diameter, with about 40% heartwood in the basal stem section, after about 15–20 years. With improved silviculture, including



*S. yasi* grown on the edge of a *Pinus caribaea* woodlot. PHOTO: L. THOMSON

more light through early thinning of pines and inclusion of some better host species, the growth rates would be enhanced. It is estimated that trees produce about 1–2 kg (2.2–4.4 lb) of heartwood each year from age 10 years. Therefore, a conservative estimate would be that a 20–25-year-old yasi tree, growing under good conditions, can produce 15–30 kg (33–66 lb) of heartwood (including from roots).

### Crop/tree interactions

The pine provides a good physical environment for the sandalwood, i.e., good shelter and intermediate light levels that encourage good stem form.

### Spacing

Pines are planted at 4 x 3 m (13 x 10 ft), or 833 stems per hectare (340 stems/ac). The sandalwood is interplanted with pine, preferably when the pines are 3 years old (although this could be done when the pines are between 2–4 years) Sandalwood could be planted between every second row and at a spacing of 8 x 6 m (26 x 20 ft), or about 208 stems per ha (84 stems/ac). Ideally, the pine rows would run north-south to allow maximum sunlight to fall on the smaller sandalwoods. The pines should be thinned (at least once) and heavily pruned to produce better quality and bigger sawlogs, and to provide a more open stand that is favorable to growth of sandalwood. Smaller nitrogen-fixing trees, such as *Calliandra*, *Casuarina*, *Sesbania*, *Gliricidia*, *Cajanus*, and *Citrus* ought to be included in this system.

## PUBLIC ASSISTANCE AND AGROFORESTRY EXTENSION

Extension offices for agroforestry and forestry in the Pacific: <http://www.traditionaltree.org/extension.html>

Organizations that have special sandalwood extension programs include Department of Forests, Vanuatu, Department of Forestry, Fiji, and Conservation and Forestry Division, Tonga.

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## *Santalum austrocaledonicum* and *S. yasi* (sandalwood)

**Author:** South Pacific Regional Initiative of Forest Genetic Resources (SPRIG) Project, SPC Forestry Program, Suva, Fiji (current contact info: IPGRI, Via dei Tre Denari 472/a, 00057 Maccarese (Fiumicino), Rome, Italy; E-mail: [L.Thomson@cgiar.org](mailto:L.Thomson@cgiar.org)).

**Acknowledgments:** The author and publisher thank Dale Evans, Tony Page, Jacques Tassin, and Art Whistler for their input. Photo contributions from Mark Merlin and Tony Page are greatly appreciated.

**Recommended citation:** Thomson, L.A.J. 2006. *Santalum austrocaledonicum* and *S. yasi* (sandalwood), ver. 2.1. In: Elevitch, C.R. (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai'i. <<http://www.traditionaltree.org>>.

**Sponsors:** Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE) Program; SPC/GTZ Pacific-German Regional Forestry Project; USDA Natural Resources Conservation Service (USDA NRCS); State of Hawai'i Department of Land & Natural Resources Division of Forestry & Wildlife; and the USDA Forest Service Forest Lands Enhancement Program. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2002-47001-01327.

**Series editor:** Craig R. Elevitch

**Publisher:** Permanent Agriculture Resources (PAR), PO Box 428, Hōlualoa, Hawai'i 96725, USA; Tel: 808-324-4427; Fax: 808-324-4129; E-mail: [par@agroforestry.net](mailto:par@agroforestry.net); Web: <<http://www.agroforestry.net>>. This institution is an equal opportunity provider.

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